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# Effects of fertilisers on vegetation of ultrabasic terraces (1965-2010): Isle of Rum, Scotland

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**ABSTRACT**

An experiment was set up in 1965 on the Isle of Rum to determine the reasons for poor vegetation cover on an exposed mountain ridge. Suggested hypotheses related to effects of grazing herbivores, site exposure or soil infertility. To test one of these, a 100 $m^2$ experimental plot was subjected to a fertiliser regime over a period of three years with a vegetation survey and soil analysis conducted at the outset of the research period (1965), in 1969 and in 1996. Plant cover within the experimental plot increased from 5 % (1965) to 100 % (1996), and was maintained at this level in a recent monitoring (2010). A change from acidophilic plants dominated by heather to a grass/moss assemblage was also recorded within the plot over the monitoring period. Within an unfertilised control plot set up in 1996, plant cover had increased from 25 % to 50 % (2010), although there was little change in composition of plant species.

**Key words**: Soil nutrients, plant cover, Inner Hebrides, grazing herbivores, long-term trends, ultra-basic terraces.

## INTRODUCTION

Higher plants grow where conditions permit, but some basic requirements must usually be met. A soil, or a substrate, capable of supporting root structures must be present, suitable nutrients, light and water need to be available and prolonged existence must allow for vegetative or sexual reproduction within acceptable climatic conditions. In 1965, on the Isle of Rum, Inner Hebrides, an experiment was set up to determine potential reasons for poor vegetation cover on an exposed mountain ridge (Ferreira & Wormell 1971). These authors suggested that grazing herbivores, red deer (*Cervus elaphus*) and feral goats (*Capra hircus*), site exposure (at 650 m) or the infertility of the soil (derived from ultrabasic rocks) might be causal factors. To test one of these hypotheses, a single 10 x 10m experimental plot was subjected to a fertiliser regime over a period of three years. This involved the following additions: August 1965, N (1125 kg $ha^{-1}$), P (500 kg $ha^{-1}$) and K (500 kg $ha^{-1}$); April 1967 and 1968, N (250 kg $ha^{-1}$) P (235kg $h^{-1}$) K (208 kg $ha^{-1}$) and Ca (470 kg $ha^{-1}$). No reason was given for the use of only one experimental plot with no control (Ferreira & Wormell 1971), however the constraints of the site in terms of altitude, remoteness and effort of transporting fertiliser to the site may well account for this.

A vegetation survey was conducted at the outset of the research period (1965) and after a period of four years (Ferreira & Wormell 1971). Thereafter, the site remained almost undisturbed until revisited in 1996 and monitored by Wilson *et al.* (1998). These authors also pegged the corners of and set up four additional plots (each 10 x 10m), close to the original (Wormell) plot. The newer plots had single applications of nitrogen, potassium or phosphorus with a control plot having no nutrient additions. Documented research on soil fauna in this location is very limited, however, Butt & Lowe (2004), sampling for earthworms on Rum, found a density of 17 individuals $m^{-2}$ (represented by 2 epigeic earthworm species) in the Wormell fertiliser plot, compared with an adjacent (control) area which yielded no earthworms.

The current investigation, undertaken in 2009 and 2010, revisited the fertiliser plot and surrounding area to try and establish recent vegetation developments. Specific objectives were:

- To record plant cover on fertilised and control plots and compare results with previous findings;
- To sample soils and draw comparisons with previous findings;
- To use the results, with other data to predict the cause of vegetation change on the exposed experimental site.

### *Site Details*

The Isle of Rum lies in the Inner Hebrides, 21 km off the west coast of Scotland. Since 1957, the whole island, of 10,650 ha, has been a National Natural Reserve, and is currently owned and managed by Scottish Natural Heritage (SNH). The natural and cultural history of the island is well documented (e.g. Clutton-Brock & Ball 1987; Magnusson 1997; SNH 2011) but critical details are that domestic grazing animals are restricted to a herd of Highland cattle *(Bos taurus)* and a collection of Rum ponies *(Equus caballus)* (Gordon *et al.* 1987), kept in lowland areas. A substantial population of red deer is present on Rum. Although reduced in recent years, from 1,200-1,700 of the last century (Clutton-Brook & Guiness 1987), Payne (2003) reported approximately 1,000 animals and this level has been maintained to date. Feral goats also graze the upland areas of the island but smaller grazing mammals such as rabbits and hares are absent from Rum. However, a study between 1958 and 1970 using controlled plots on the grasslands and heaths of the island have shown that reduced grazing increases the plant litter and taller vegetation which reduces the diversity of vegetation. The management plan of the island was to maintain the high floristic diversity of all vegetation types present which led to the annual cull of red deer being severely reduced (Ball 1974).

The fertiliser plot experimental site is on the exposed Barkeval-Hallival ridge (Nat Grid Ref: NM39260 96433) comprised of peridotite and allivalite igneous ultra-basic rocks, with many exposed rocks (Ragg & Ball 1964). The thin soils formed over these base rocks have high levels of magnesium, low levels of calcium and exceptionally low levels of phosphorus; calcifuge plants often dominate here due to the low levels of calcium within the soil. There is evidence that the oceanic climate on Rum, with an annual rainfall ranging from 1,397 to 3,302 mm (Ragg & Ball 1964), is warming. The extent of snow cover and sea ice in the Northern Hemisphere has declined since 1979 (Dery & Brown 2007; Serreze *et al.* 2007) leading to increased plant growth in northern high latitudes (Myneni *et al.* 1997). On Rum, the oestrus date and parturition date in female red deer, and antler cast date, antler clean date, rut start date and rut end date in males has advanced between 5 and 12 days across a 28 year study period with the plant growth in spring and summer (growing degree days) explaining a significant amount of variation in all six of these phonological traits. (Moyes 2011).

## METHODS

*Fertiliser Plots*

An initial survey in 2009 (26-29$^{th}$ April) sought to locate the plots set up by Wilson *et al.* (1998), but found that many of the metal pegs used to mark out the more recent treatments had been dislodged/removed and exact positions could not be deliniated with any confidence. Surface water was also seen to run from the location of the potassium-enhanced plot into the area where the phosphorus plot was positioned. It was therefore determined that it was unsound to survey these plots, and only work within Wilson *et al.*'s (1998) control plot and the original (Wormell) plot was undertaken. The main investigation of these two plots was undertaken in 2010 (24-28$^{th}$ May).

*Plant Cover.*

The 2009 survey of the original (Wormell) and the control plot was undertaken following the methodology described by Gilbert & Butt (2009). This made use of digital photography of vegetation within 0.5 x 05m quadrats. Although this size of quadrat was different to the original surveys (1 x 1m) the area surveyed was the same (4m$^2$). Images were manipulated in Adobe Photoshop (2000) to produce a 'squared' image and the percentage cover of each plant species was estimated by means of digital superimposition of a grid on to the image. In 2010 (24-28$^{th}$ May), a more traditional vegetation survey of both plots was conducted using a point quadrat (100 points m$^{-2}$) as described by Chalmers & Parker (1989). Here, only the first plant species contacted was recorded per point, to provide an estimate of mean percentage cover for each species over the whole plot. This was the same sampling technique used in earlier (1969, 1996) surveys of this area and the same area of experiment plot was sampled (4m$^2$).

*Soil Sampling and Analyses*

Soil cores (0.05 m diameter) were collected using a random sampling scheme to a depth of 0.15 m in the experimental (n=16) and control (n=16) plots, and sub-divided into samples at 0.05 m depths. Due to the shallowness of soil only eight of the control plot sample cores achieved the depth of 0.15 m in contrast to all experimental plot samples. Each soil horizon was described by reference to a Munsell soil colour chart (1992). Soil bulk density was determined after samples were air dried, sieved to <2 mm and calculated as mass of air dry soil per unit volume, corrected for stone content. Soil collection and soil analyses duplicated as closely as possible that utilised by Ferreira & Wormell (1971) and Wilson *et al* (1998). However, in the current survey nutrient content of soils was not analysed by the authors, but undertaken at an accredited laboratory (Macaulay Land Use Research Institute).

## RESULTS

*Plant Cover*

The 2009 survey using digital photography showed the fertiliser plot to be completely vegetated, except for areas covered by a few large rocks that protruded through the plants. This showed no change since the survey of 1996. The photographic survey of the control plot showed a vegetation cover of 48 %, an increase from 25.2 % in 1996, very similar to the 2010 point quadrat survey of 50%. Table 1 shows the species list for plants found in both the fertiliser plot and the control plot, obtained from point quadrat survey in 2010. Comparative results from previous surveys are also provided in Table 1. Results from 2010 also confirmed the 2009 photographic survey results that the fertiliser plot is still 100 % vegetated, an increase from 5-10 % vegetation cover recorded prior to fertiliser addition in 1965.

Calcifuges such as *Calluna vulgaris* (L.) Hull (heather) and *Rhacomitrium lanuginosum* (Hedw.) Brid. reported in 1998, were not recorded within the fertiliser plot in the current survey. Grasses and mosses accounted for the majority of the plant cover within the plot with *Hypnum cupressiforme* (Hedw), *Rhytidiadelphus squarrosus* (Hedw.) Warnst. and *Festuca vivipara* (L.) offering most of the cover. *Anthoxanthum odoratum* (L.) and *Taraxacum officinale (Weber.)* first observed in 1996 but not recorded in the survey, accounted in 2010 for 9 % and 0.5 % of the cover respectively.

*Peltigera spp* was observed for the first time within the fertiliser plot during the current survey.

| | | Fertiliser Plot – set up in 1965 | | | | Control – set up in 1996 | |
|---|---|---|---|---|---|---|---|
| | | 1965 DAFOR | 1969 DAFOR | 1996 % cover | 2010 % cover | 1996 % cover | 2010 % cover |
| *Agrostis capillaris* L. **Common Bent** | M | f | cd (15%) | 7.75 | 2.0 | 1.46 (5.9) | 2.5 (5.2) |
| *Alchemilla alpina* L. **Alpine Lady's mantle** | D | - | - | • | - | - | - |
| *Antennaria dioica* (L.) Gaertn. **Mountain Everlasting** | D | o | r | • | - | 0.77 (3.1) | 0.5 (1.05) |
| *Anthoxanthum odoratum* L. **Sweet Vernal-grass** | M | - | - | • | 8.75 | - | - |
| *Arabis petraea* (L.) Lam [*Cardaminopsis petraea* (L.) Hiit]. **Northern Rock-cress** | D | r | r | • | - | - | - |
| *Armeria maritima* (Mill.) Willd. **Thrift** | D | - | - | • | 0.5 | - | - |
| *Barbula rigidula* (Hedw.) Mitt. | B | - | a | - | - | - | - |
| *Calluna vulgaris* (L.) Hull **Heather** | D | f | o | 0.25 | - | 10.62 (42.1) | 23.75 (49.75) |
| *Campylopus atrovirens* De Not. | B | r | - | - | - | - | - |
| *Carex binervis* Sm **Green-ribbed Sedge** | M | - | r | - | - | - | - |
| *Carex viridula* [*demissa*] Michx. **Yellow-sedge** | M | r | - | - | - | 0.46 (1.8) | 12.75 (26.70) |
| *Carex panicea* L. **Carnation Sedge** | M | - | - | - | - | 0.23 (0.9) | |
| *Carex pilulifera* L. **Pill Sedge** | M | - | r | - | - | - | - |
| *Cerastium fontanum* (holost.) Baumg. **Common Mouse-ear** | D | - | r | 0.25 | 1.0 | 0.03(0.1) | 0.25 (0.52) |
| *Cladonia uncialis* (L.) Weber | B | - | - | 0.25 | - | 0.03(0.1) | |
| *Cynosurus cristatus* L. **Crested Dog's tail** | M | - | - | - | - | - | - |
| *Danthonia decumbens* (L.) [*Sieglingia decumbens*] **Heath grass** | M | o | r | - | - | - | - |
| *Deschampsia flexuosa* (L.) Trin. **Wavy Hair-grass** | M | f | a | • | - | 0.20 (0.7) | - |
| *Dicranum scoparium* Hedw. | B | - | - | 3.75 | - | - | - |
| *Euphrasia sp.* L. **Eyebright** | D | o | - | 0.25 | - | 0.03 (0.1) | |
| *Festuca rubra* L. **Red Fescue** | M | - | r | • | - | - | - |
| *Festuca vivipara* (L.) Sm. **Sheep's fescue** | M | f | cd (15%) | 27.75 | 30 | 1.72 (6.8) | 3.0 (6.28) |
| *Hypnum cupressiforme* Hedw. | M | o | - | 16.25 | 32 | - | - |
| *Juniperus communis alpine*, Celak. **Alpine Juniper** | G | r | - | - | - | - | - |
| *Molinia caerulea* (L.) Moench. **Purple moor-grass** | M | o | - | - | - | - | - |
| *Nardus stricta* L. **Mat-grass** | M | - | - | • | 0.5 | 0.33 (1.3) | - |
| *Oligotrichum hercynicum* (Hedw.) Lam & Cand. | B | - | o | - | - | - | - |
| *Plantago lanceolata* L. | D | - | - | • | - | - | - |
| *Plantago maritima* L. | D | f | a (5%) | 3.00 | - | 2.15 (8.5) | 2.00 (4.19) |
| *Polygala serpyllifolia* Hose. **Heath Milkwort** | D | o | - | • | - | 0.03(0.1) | - |
| *Polytrichum alpinum* Hedw. | B | - | o | 5.25 | 7.5 | - | - |
| *Polytrichum piliferum* Hedw. | B | o | - | - | - | - | - |
| *Polytrichum urnigerum* Hedw. | B | - | a | - | | - | - |
| *Potentilla erecta* (L.) Rausch. **Tormentil** | D | f | o | 1.5 | 0.25 | 0.72 (2.9) | • |
| *Rhacomitrium lanuginosum* (Hedw.)Brid. | B | f | - | 0.5 | - | 3.36 (13.3) | 0.75 (1.57) |
| *Rhytidiadelphus squarrosus* (Hedw.) Warnst. | B | r | - | 18.5 | 11.75 | 0.05 (0.2) | 0.5 (1.05) |
| *Rubus saxatilis* L. **Stone Bramble** | D | o | f | 0.25 | - | 0.08 (0.3) | - |
| *Selaginella selaginoides* (L.) Beauv. **Lesser Clubmoss** | B | r | r | • | - | 0.05 (0.2) | - |
| *Silene acaulis* (L.) Jacq. **Moss Campion** | D | - | - | • | - | - | - |
| *Solidago virgaurea* L. **Goldenrod** | D | o | o | • | - | 0.21 (0.9) | - |
| *Succisa pratensis* Moench **Devil's-bit Scabious** | D | o | - | - | - | - | - |
| *Taraxacum officinale* Weber. | D | - | - | • | 0.5 | - | - |
| *Thymus polytrichus* [*praecox* Opiz] **Wild Thyme** | D | f | f | 11.75 | 5.25 | 2.13 (8.5) | 1.75 (3.66) |
| *Trichophorum cespitosum* (L.) Hartm. **Deergrass** | M | - | - | - | - | 0.41 (1.6) | |
| *Vaccinium myrtillus* L. **Bilberry** | D | - | - | • | • | - | - |
| *Viola riviniana* Reichb. **Common Dog-violet** | D | o | o | 2.75 | | 0.15 (0.6) | • |
| *Peltigera spp* | L | - | - | - | • | - | - |
| Total plant cover (%) | | 5 - 10 | 60 | 100 | 100 | 25.2 (100) | 50.25 (100) |

**Table 1.** Plant species recorded in the fertiliser plot and control plot at an altitude of 650 m on the Barkeval-Hallival ridge, Isle of Rum. Results from previous studies (Ferreira and Wormell 1971; Wilson et al. 1998) also provided. Figures in parentheses are percentage of total vegetation cover, • denotes species that were observed but not recorded, cd =co-dominant. (M=Monocotyledonous, B=bryophyte, D=dicotyledonous, P=pteridophyte, L=lichen, G=Gymnosperms, [ ] = former names). English names (Stace 2010).

The vegetation cover of the fertiliser plot changed considerably since 1965 and contrasts with the control plot, delineated by Wilson *et al.* (1998). Overall, vegetation cover of 50 % was recorded in the control plot, an increase from the 25 % noted in 1996, the dominant vegetation was heather with 24 % cover.

*Soils*

Soil profiles of the untreated (control) plots in 1965, 1996 and 2009 are very similar with approximately 0.03 m of very dark brown organic matter (10YR 2/2) above a yellowish-brown mineral horizon (10YR 5/4). This profile was not uniform across the control plot in 2009, with the organic horizon ranging from 0 - 0.1 m, due to erosion and deposition. The horizon below the fertiliser plot was very different, with a deeper organic horizon to 0.04 m (10YR 2/1) and organic staining (10YR 2/2) down to 0.08 m, above a similar yellowish-brown mineral horizon (10YR 5/4). This was deeper than records from 1996, when the organic horizon reached to a depth of 0.03 m with staining to 0.06 m. Soil bulk density within both the fertiliser plot and the control plot increased with depth, although both results recoded were generally lower than those reported by Wilson *et al.* (1996) except in the control plot at 10 – 15 cm (Fig. 1).

Fig. 2 provides results from the fertiliser plot before treatment (1965), in 1996 and 2010. Most measurements showed an increase over time of; organic matter, pH and nutrients, which generally reduced with increasing depth. The exception was phosphorus, as Wilson *et al.* (1998) previously recorded a much higher level. There was also an increase in magnesium recorded in the upper section of the soil cores (0 - 0.05 m) extracted from the fertiliser plot.

Results from the control plot, in addition to the fertiliser plot before treatment, are given in Table 2. Here, within the upper 0.05 m, there has been an increase in organic content, pH and some nutrients, although no phosphorous was recorded in 2009. A much higher level of magnesium (135 mg $kg^{-1}$) was also recorded.

Although comparison of nitrate content of the plots was not possible, due to different analyses undertaken, the results are presented for possible comparison in future studies. Fertiliser plot; 0 - 0.05, 0.05 - 0.10, 0.10 - 0.15 m contained 1.65, 4.78, 6.66 mg $kg^{-1}$ respectively (n=16). The control plot contained 18.48 mg $kg^{-1}$ at 0 - 0.05 m (n=16).

## DISCUSSION

Results from the original (Wormell) plot suggest that even after 45 years the fertiliser continues to have an effect. Acidophiles within the plot continue to decline, for example, reduced cover of heather was reported by previous authors but not recorded within the current survey. A similar reduction for heather has been reported on heathland sites that have received fertiliser applications (Aerts 1993). Here on Rum, there was no evidence of an increase in heather, as previously suggested by Wilson *et al.* (1998). However, grass and moss species (*F. vivipara* and *H. cupressiforme* specifically) dominate the plot. (There is also increased pH and nutrient content of the soil.)

The ultrabasic rocks, with low plant nutrients, but high concentrations of magnesium, now appear to have little effect on the plant species in the area. However, a high recording of magnesium (675.4 mg $kg^{-1}$) was found in the upper (0 - 0.05 m) cores from the fertiliser plot. This may in part be wind-borne material from the surrounding unvegetated areas, or from the analysis method used. However, high concentrations of potentially toxic elements, such as magnesium, have been shown to have little effect on vegetative growth (Looney and Proctor 1990).

Vegetation cover within the control plot has increased from 25 to 50 % (1996-2010) and from (at best) 10 % in 1965. This, seemingly un-manipulated increase, may be accounted for by a number of factors. The known reduction in deer number, particularly in recent years, may be partially responsible, with less than half the number of 15 years ago, now grazing on Rum (Payne 2003). This may be particularly important at the experimental plot site, as this green square at altitude of 650m must act as an attraction to herbivores. In addition, enhanced climatic conditions (e.g. Moyes 2011; Myneni *et al.* 1997) may have led to a prolonged growth period each year.

The assumption by Wilson *et al.* (1998) that heather had influenced pH in the control plot was not confirmed in the current survey. Although cover of heather had increased (10.6 to 23.7 %), pH had also increased from 4.9 to 5.7. This may be accounted for by the increased vegetation cover reducing leaching with more minerals and nutrients held in the substrate beneath the plants.

It was unfortunate that the additional (single element) fertiliser plots set up by Wilson *et al.* (1998) were considered unfit for survey. Continued monitoring of these plots might have led to a clearer understanding of how specific nutrients affect plant growth at an altitude of 650m in an exposed environment. However, it does demonstrate that experiments of this type on an exposed mountain ridge need to be robust in their design and execution.

That earthworms are present in the fertiliser plot (Butt & Lowe, 2004) is not unexpected, as these animals require a minimum level or organic matter (as shown in Fig. 2). Such animals are not uncommon at this altitude on these rocks/soils but are usually associated with natural “greens” created through fertiliser addition from nesting bird faeces (e.g. Furness, 1991). Further research in this area is ongoing (Callaham *et al.*, in press).

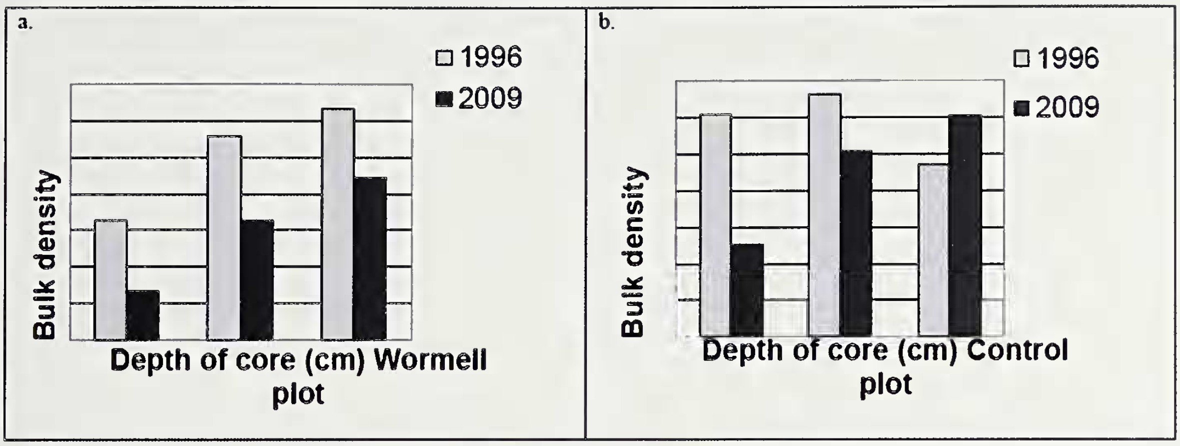


Fig. 1. Bulk density soil measurements from (a) (Wormell) fertiliser plot and (b) control plot.

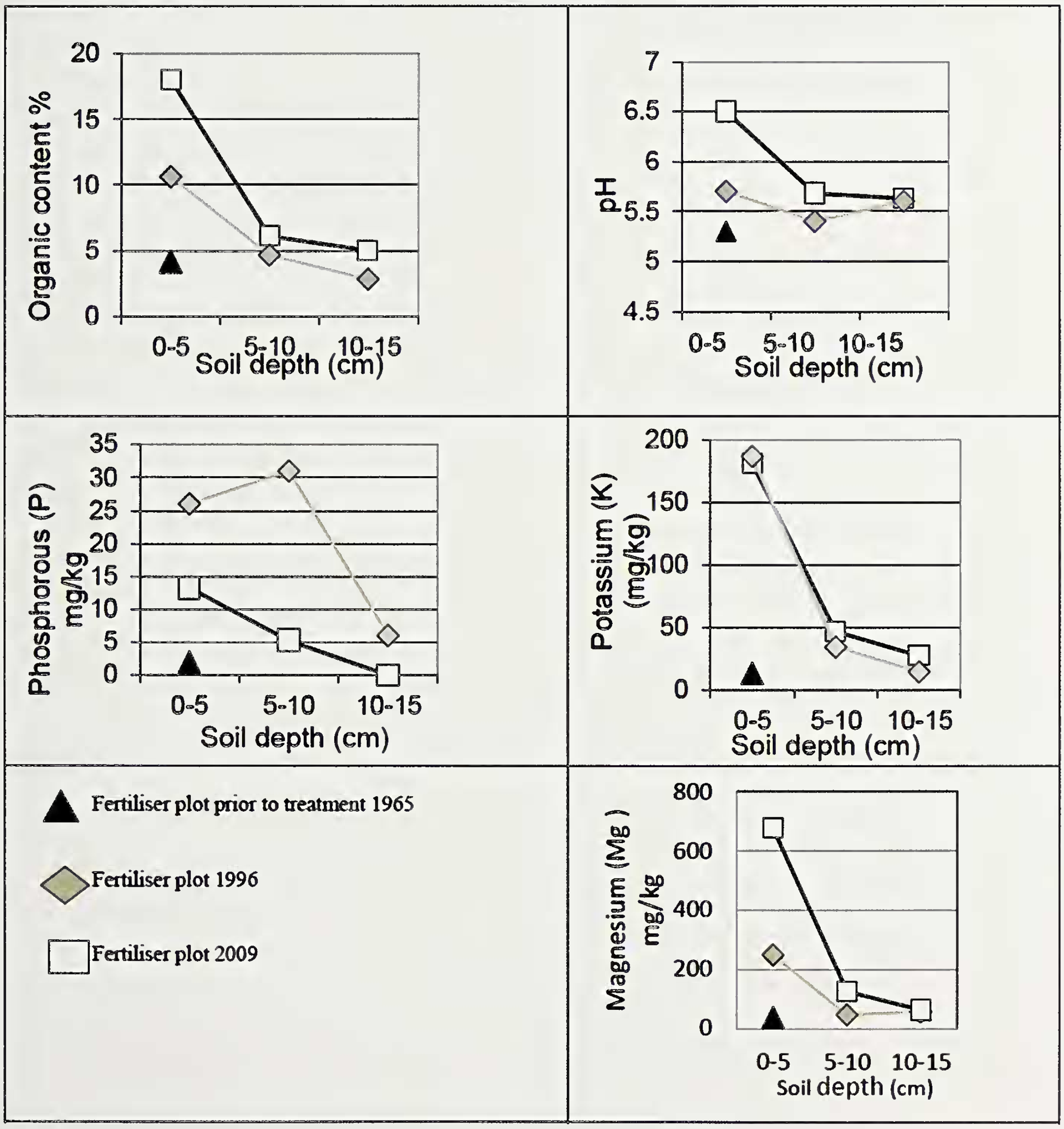


Fig. 2. Soil analyses of the (Wormell) fertiliser plot over a 45 year period.

| | Organic matter content | pH | Phosphorous mg kg$^{-1}$ | Potassium mg kg$^{-1}$ | Magnesium mg kg$^{-1}$ |
|---|---|---|---|---|---|
| Fertiliser plot pre treatment | 4.15 | 5.3 | 2.0 | 13 | 37 |
| Control Plot 1996 | 4.85 | 4.9 | 3.1 | 29 | 20 |
| Control Plot 2009 | 6.4 | 5.7 | 0.0 | 41 | 135 |

**Table 2.** Soil data derived from control plots over a 45 year period, only results of the upper 5 cm of the core provided.

It is currently difficult to assess the direct influence brought about by reduced levels of grazing, and/or the increase in temperature on vegetation growth days on the fertiliser plot. Increased vegetation cover within the control plot indicates that there has been some effect, as this is not directly related to historical fertiliser addition. Further carefully designed experiments, to address Wormell's original hypotheses may still be warranted, to fully determine limiting factors associated with plant growth of patchy herb-rich *Calluna* heath/grass-dominated swards at altitude on Rum.

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